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The cover image is a composite. The left side features a close-up of a green, segmented caterpillar with white spots and spiky protrusions, crawling on a green leaf. The right side shows a field of lush green kale plants with large, deeply lobed leaves. In the background, there are tall, thin trees with green foliage under a bright sky. A semi-transparent white box is overlaid on the right side, containing the title and author information.

Assessing the effects of agroforestry practices on biological control potential in kale (*Brassica oleracea acephala*) plantations in Western Kenya

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Abstract

Agricultural intensification and extension at the expense of forests are known to have a negative impact on biodiversity and ecosystem services. In Sub-Saharan Africa (SSA), agriculture provides livelihoods for most of the population and forestry is an important additional income. Agroforestry practices may help to compensate for loss of biodiversity. Pests are an important constraint to agricultural production and their biological control is affected by environmental degradation. Management practices such as alteration of the field micro-environment and increases in landscape complexity can be efficient non-chemical methods for reducing pest damage. In this study, I examine how the implementation of agroforestry influences biological control in kale (*Brassica oleracea* var. *acephala*) plantations in Western Kenya.

Twenty fields, either shaded or open, were selected at four settlements in the Trans-Nzoia district of Kenya. Landscape complexity was defined as the percentage of wooded vegetation within a 50 m radius. Pesticide use, mulching practices and the amount of rainfall were recorded as additional explanatory variables. Predation was assessed by (1) egg removal rates, (2) bird exclusion, and (3) predation marks on plasticine caterpillars. Activity density of ground-dwelling predators was assessed with pitfall traps and foliage-dwelling pests and predators were counted on the plants. Aphid parasitism rates were also estimated by counting live aphids and aphid mummies. The effect of shade and landscape complexity, pesticide use, mulching and rainfall was tested by running generalized linear models and selecting the best models based on Akaike Information Criterion adjusted for small sample-sizes.

Presence of shade-trees at the local field level was found to be effective in reducing population of both surveyed pests and in increasing aphid parasitism rates and caterpillar predation by birds. Neither the proportion of wooded vegetation in the landscape nor the interaction between local shade and landscape scale tree cover were retained as significant explanatory variables. However, pesticides negatively influenced aphid abundances, predator abundances and egg removal rates while positively influencing caterpillar populations.

I conclude that in kale agro-forestry systems of Western Kenya, local management of shade is effective in increasing biological control of pests, but I found no evidence that the proportion of trees in the landscape is important. This can be explained by the small-scale of the analysis and should be investigated with larger scale and stronger differences between agroforestry versus conventional systems. The negative effect of pesticides is also important to note and should be further investigated in order to improve the sustainability of farming practices.

Keywords: biological control, kale, agroforestry, shade, Kenya

Table of contents

Abstract	iii
Table of contents	iv
Introduction	1
Agricultural intensification and its consequences	1
Agriculture and forestry in Sub-Saharan Africa	1
Animal pests & pesticide use	2
Biological control.....	3
Kale as a study system	3
Agroforestry practices	5
Aim and hypotheses	6
Material and methods.....	6
Farm selection	6
Assessment of agroforestry and landscape complexity	7
Ground and foliage-dwelling arthropods.....	8
Survey of ground-dwelling predator fauna	8
Survey of foliage-dwelling pest and predator fauna	8
Predation by ground-dwelling arthropods on Diamondback moth eggs (<i>Plutella xylostella</i>)	9
Predation by birds on aphids and caterpillars	9
Predation on caterpillars	10
Parasitism on aphids	10
Statistical analysis	10
Results	11
Ground and foliage-dwelling arthropods.....	11
Survey of ground-dwelling predatory fauna	11
Survey of foliage-dwelling pest and predatory fauna.....	12
Predation by ground-dwelling arthropods on Diamondback moth eggs (<i>Plutella xylostella</i>)	13
Predation by birds on aphids and caterpillars inferred from exclusion cages	14
Predation on surrogate caterpillars	14
Parasitism on aphids	15

Discussion	16
Effect of shade in reducing pest populations	16
Possible improvements to the study design	17
Possible ways of improving biological control in agroforestry systems	18
Predation by birds	19
Effect of pesticides	19
Conclusion	20
Acknowledgements	21
References.....	21
Appendix 1: Example of landscape analysis buffer zones	25
Appendix 2: Examples of predation and parasitism marks on surrogate caterpillars	26
Appendix 3: Summary of the retained models	27
Appendix 4: Effects of shade, proportion of wooded vegetation and their interaction.....	29

Introduction

Agricultural intensification and its consequences

Agricultural expansion is one of the main causes of the worldwide environmental degradation which has been a growing concern during recent decades. This has led to the promotion of environmental sustainability as one of the Millennium Development Goals (United Nations 2013). Nowadays, cultivated systems – including pastures – cover 24% of the earth's land surface (Millennium Ecosystem Assessment 2005b), a percentage that has been increasing drastically since the industrial revolution (Meyer and Turner 1992). This conversion to agriculture is not believed to change in the short term (Millennium Ecosystem Assessment 2005a) and mainly takes place at the expense of forests (Foley et al. 2005). The consequences of agricultural expansion vary from biodiversity loss to soil degradation and pollution, to mention only few effects (Matson et al. 1997, Vitousek et al. 1997).

Intensification of agricultural practices and consequent simplification of the landscape is another cause for biodiversity loss (Foley et al. 2005). In combination with agricultural expansion, it leads to habitat loss and reduced connectivity between the remaining patches for wild species' populations, thus rendering them more sensible to further disturbances (Millennium Ecosystem Assessment 2005a). In general, high biodiversity is believed to increase the resilience of the ecosystems and provide an insurance against environmental variability, as some alternative species will always be present to take over the function provided by a failing one (McNaughton 1977, Naeem et al. 1994, Tilman and Downing 1994, Yachi and Loreau 1999). The current loss of biodiversity thus increases the sensitivity of agro-ecosystem. The loss of biodiversity also has the potential to alter ecosystem services (Naeem et al. 1994). Many of these, such as soil formation, pollination and pest regulation, are of high importance to agricultural production (Bommarco et al. 2013). Degradation of ecosystem services could substantially limit production or increase its cost. A minimum estimation of the value of ecosystem services is about US\$33 trillion per year worldwide, of which \$US19 trillion is closely linked to food production (Costanza et al. 1998). The impact of agriculture on biodiversity is likely to trigger a negative feedback which could decrease agricultural efficiency in the long-term (Matson et al. 1997), and a change towards more sustainable agronomical practices, including management of ecosystem services, is therefore required (Scherr and McNeely 2008, Bommarco et al. 2013).

Agriculture and forestry in Sub-Saharan Africa

Increasing the sustainability and efficiency of agriculture is especially crucial in countries where the main part of the population is still dependent on farming for its livelihood. In Sub-Saharan Africa (SSA), 55.2% of the population is dependent on agriculture for their incomes, compared to 5.3% in Europe and 0.7% in the USA (FAO 2012). The Millennium Development Goals of halving

poverty by 2015 have been reached worldwide with the exception of SSA, where the number of people earning less than \$US1.25 a day has been rising steadily since 1990 (United Nations 2013). This is reflected by hunger, where once again progress is slower in SSA countries than in the rest of the world (United Nations 2013). Further development of agriculture is crucial to decrease poverty and hunger as it has been seen to have strong impacts on welfare (World Bank 2008, Wambugu et al. 2011, FAO 2012). Constraints to agricultural growth in SSA the last decades include the neglect of research during agricultural market reforms (Kherallah et al. 2000, cited by Wambugu et al. 2011) and a focus on large-scale farms, which were considered essential to modernize agriculture (Djurfeldt et al. 2005). However, small-scale farming is the norm in SSA, where 80% or the continent's farms are smaller than 2 ha (FAO 2009, Jirström et al. 2011), compared to average farm sizes of 15 and 180 ha in Europe and the United States, respectively (European Commission 2013). The focus should consequently be shifted from large-scale farms to small-scale farms in SSA as improvements on the latter affect the majority of the population (Djurfeldt et al. 2005, FAO 2009).

If agriculture is the main provider of livelihoods in Kenya, forestry often contributes to the small farmers' incomes and thus helps reducing poverty (Mbuvi and Boon 2009, Kabubo-Mariara 2013, United Nations 2013). Forests contribute about 10% of the total income of Kenyan's households, by providing resources such as fuel, construction materials, wild fruits and vegetables, honey and medicinal plants or by providing shaded grazing areas or sites for planting crops (Mbuvi and Boon 2009, Kabubo-Mariara 2013). In Kenya, forests cover 1.03 million ha – 1.8% of the total surface area –, none of them being pristine due to legal and illegal logging and agricultural practices in the past (Bhagwat et al. 2008, Kabubo-Mariara 2013). Thus governmental programs support forest plantations, which now cover 170'000 ha of land, 0.3% of the area of the country (Kabubo-Mariara 2013). If conservation of forests in protected areas is important, the integration of forest patches in agricultural landscape potentially helps to compensate for the loss of biodiversity and ecosystem services provided by natural forests. Forest plantations decrease the pressure on protected forest by offering alternatives to illegal logging and serve as corridors for biodiversity (Bhagwat et al. 2008).

Animal pests & pesticide use

Agricultural pests and weeds constitute an important constraint to agricultural production in Africa, where they are considered one of the major limitations to productivity (Abate et al. 2000). Worldwide, they cause between 26% and 80% of crop losses despite protection measures (Oerke 2006). While animal pests account only for 18% of these losses, the efficiency of their control is much lower than that of weeds (Oerke 2006), thus leaving more space for improvements.

In current conventional agriculture, the primary approach to tackle animal pest problems is chemical pesticides. However, pesticide use induces several

problems ranging from negative environmental effects to threats to human health (Pimentel et al. 1992, Ohayo-Mitoko et al. 2000, Millennium Ecosystem Assessment 2005b). Their efficiency can also be questioned as their increased use during the last four decades has not resulted in decreased losses due to pests (Oerke 2006). In SSA, agriculture tends to be more traditional, including pest management practices such as crop rotation, intercropping with insect-detering plants, hand weeding or smoke (Abate et al. 2000). A shift towards increased use of pesticides is however taking place, mainly because they are seen as a way to intensify agriculture and decrease poverty (Abate et al. 2000, Wambugu et al. 2011). This shift is largely supported by governments, with measures such as subsidies for agro-chemicals, but pesticide still are often a large part of the farmers' expenses in SSA countries (Wambugu et al. 2011). The negative impacts are increased by local conditions, such as the over-simplification of instructions leading to unsecure application methods, the use of pesticides on non-target pests or the use of obsolete and/or banned products (Nyambo et al. 1996, Abate et al. 2000).

Biological control

One of the ecosystem service affected by biodiversity loss is pest regulation by natural enemies (Millennium Ecosystem Assessment 2005b). Biodiversity loss does not only affect species in natural habitats, but also many pest natural enemies in agricultural landscapes, such as birds or arthropod predators and parasitoids. For instance, agricultural birds are decreasing at higher rates than forest birds (EBCC 2013) and arthropod predators are sometimes negatively impacted by pesticides, albeit not being targeted (Flexner et al. 1986, Theiling and Croft 1988). Landscape simplification, with resulting biodiversity loss, have thus increased the vulnerability to pest attacks (Altieri and Letourneau 1982).

One of the sustainable approaches to pest management is conservation biological control, defined as an "[alteration of] habitats to improve availability of the resources required by natural enemies for optimal performances" (Landis et al. 2000). Higher landscape complexity could thus boost natural predator and parasitoid populations by providing shelter for overwintering and/or oviposition, alternative food sources before pest outbreaks or habitats containing alternative host or prey (Landis et al. 2000). Even though results are variable, some studies have clearly shown that landscape complexity and the presence of trees in agricultural systems can positively affect biological control of specific pests (Perfecto et al. 2004, Bianchi et al. 2008, Tscharntke et al. 2011, Karp et al. 2013). Biological control by environmental management can also have indirect positive effects by enhancing several other ecosystem services, be it supporting, provisioning, regulating or cultural services (Fiedler et al. 2008).

Kale as a study system

Kale (*Brassica oleracea* var. *acephala*) is a leafy biennial or perennial vegetable, which provides an important share of small-scale farmers' income in Kenya (Salasya 2005). It is used both for direct consumption and as a cash crop

(Kibata 1996, Ordás and Cartea 2008, Salasya and Burger 2010). In Europe and North America, the interest in kale has increased during recent years due to its nutritional values and anti-cancer properties, thus influencing the quantity and quality demands for export to these countries (Ordás and Cartea 2008). In Kenya, 599625 tons of *Brassica* were harvested in 2011, 82% of which for local consumption (FAOSTAT 2013).

Brassica crops are known to host more pests than most crops. These pests can cause extreme damage by feeding on the plant and consequently reducing their marketability, and have the potential to destroy the entire harvest if left uncontrolled (Kibata 1996, Ordás and Cartea 2008). In Kenyan agro-ecosystems, aphids, thrips, moth caterpillars, whiteflies, leaf-beetles (Coleoptera: Chrysomelidae) and gaudy grasshoppers (Orthoptera: Pyrgomorphidae) are the most often recorded pests of kale (Ndang'ang'a et al. 2013). Kale can host five different species of aphids (Blackman and Eastop 1985) but the most common one is the cabbage aphid *Brevicoryne brassicae* (Hemiptera: Aphididae). It affects plants by causing severe leaf stunting and distortion and transmitting the cauliflower mosaic virus as well as the turnip mosaic virus (Alford and British Crop Protection Council 2000). In addition to aphids, caterpillars of several moths and butterflies (Lepidoptera) are among the most severe pests of kales. Their main effect is to decrease the foliage surface by feeding on it (Alford and British Crop Protection Council 2000). No studies are available about the abundance of pest caterpillars of kale in Kenya, but a study in Spain revealed fluctuations in their presence, with the cabbage moth (*Mamestra brassicae*) representing 48.5% of the Lepidoptera species, followed by the diamondback moth (*Plutella xylostella*, 25%) and the small white (*Pieris rapae*, 15%) (Cartea et al. 2009). The diamondback moth is however often considered as one of the major production constraint of *Brassica* sp., partly because of its worldwide distribution and high resistance to all insecticides (reviewed in Talekar and Shelton (1993); see Kibata (1996) for a Kenyan case).

Generally, these *Brassica* pests are managed with insecticides (Ordás and Cartea 2008). This is also the case in Kenya, where at least 82.8% of all farmers producing cabbage and/or kale use at least one kind of insecticide (Nyambo et al. 1996). This use of pesticides is partly due to the strong European regulations on horticultural crops produced for export, which forces the farmers to maintain low overall levels of pests (Abate et al. 2000), and partly due to the fact that pesticide use is easier than alternative control strategies (Kibata 1996). In SSA, farmers are also often caught in poverty traps where non-sustainable practices such as pesticide use are preferred over long-term investments as they bring direct gain, even though they result in loss of several ecosystem services (Swallow et al. 2009). However, kale pests have decreased due to pest management practices using environmental modification such as intercropping, which decreased the damage on marketable produce (Ogol and Makatiani 2007). Even if environmental management techniques are not widely used for pest control on kales, the presence of a high variety of pests' natural enemies,

recorded both worldwide and in Kenya, hints that such practices could be effective (Kibata 1996, Kahuthia-Gathu 2013, Ndang'ang'a et al. 2013, Santolamazza-Carbone et al. 2013). The avian fauna for instance, although often perceived by Kenyan farmers as being pests and having sometimes indeed reached pest status (Bruggers et al. 1981, Chitere and Omolo 1993, Grisley 1997), can have beneficial effects by reducing pest populations, be it aphids or chewing herbivores, either directly or by disturbing aphid mutualisms with ants (Mooney 2006, Ndang'ang'a et al. 2013). Studies on landscape effects on predation of pest insect of kale and its close relatives such as broccoli (*Brassica oleracea* var. *italica*), Brussels sprouts (*B. oleracea* var. *gemmifera*) or oilseed rape (*B. napus*) have shown the positive effects of non-crop area in the landscape on both pest predation and parasitism (Thies et al. 2003, Bianchi et al. 2008, Jonsson et al. 2012). These landscape effects can be significant from 300 m to 10 km away (Thies et al. 2003, Bianchi et al. 2008, Zaller et al. 2008, Chaplin-Kramer and Kremen 2012, Josso et al. 2013, Rusch et al. 2013). Within-field management has also been an effective method for increasing parasitism rates, but its effects are higher at low landscape complexity, indicating that high landscape diversity can mask the effects of within-field management (Thies and Tscharntke 1999, Valantin-Morison et al. 2007, Chaplin-Kramer and Kremen 2012).

Agroforestry practices

Pest management through agroforestry has received attention only recently (Rao et al. 2000, Schroth et al. 2000). Agroforestry has the potential to reduce pest damage but, by implementing perennial agroforestry practices, the farmers decrease their possibilities to conduct active pest control by traditional practices, which rely on frequent disturbances (Schroth et al. 2000). This loss of control by the farmer has to be compensated by an increase of the internal control mechanisms of the agro-ecosystem (Schroth et al. 2000). This is often the case, as *Brassica* pests have been seen to experience increased parasitism rates in the vicinity of forest areas (Bianchi et al. 2008) and studies on other crops showed a positive effect of forest patches on pest predation (Perfecto et al. 2004, Karp et al. 2013). However, the effect of tree plantations on pests and their natural enemies vary in different systems and is not guaranteed to be positive (Rao et al. 2000, Schroth et al. 2000, Altieri and Nicholls 2004). The internal control mechanisms of the agroforestry system can act both at a within-field and landscape scale. They can be triggered by changes such as the increased availability of alternative prey for natural enemies in agroforestry systems, the disturbance by trees of the crops' olfactory signals making plant location more difficult for the pests, or the alteration of the field micro-climate by increased shade and humidity and decreased wind speed and air temperature in the crops, to which predators and parasitoids are sensitive (Rao et al. 2000, Schroth et al. 2000). The interaction between local scale and landscape scale management perceived in relation to landscape complexity has also been observed when the latter was defined by the proportion of trees (Valantin-Morison et al. 2007). This

implies that tree plantations within the fields or at a close vicinity is likely to reduce pest population as long as agroforestry is not implemented at a large scale, at which point the landscape effects would overcome the field-scale ones. The difficulty to predict the consequences of tri-trophic interactions in complex agricultural systems implies that a thorough understanding of the relationships between insect pests, their natural enemies and their environment is needed (Rao et al. 2000, Altieri and Nicholls 2004).

Aim and hypotheses

The aim of this project is to get a better understanding of the relationship between trees, crop pests and natural enemies by assessing whether the biological control potential of pests in kale agro-ecosystems is enhanced by agroforestry practices compared to conventional practices. This study assessed biological control with several different methods in 20 small-scale farms with varying tree cover at local and landscape scales. I hypothesized that (1) fields shaded at a local scale would experience more predation on insect pests than open fields; (2) the proportion of wooded vegetation in the landscape would be positively correlated with predation on insect pests and (3) there would be an interaction between local and landscape scale level of shading, in which local shading would increase predation on insect pests only in landscape with a low tree cover.

Material and methods

Farm selection

Farms were selected at five different settlement schemes, namely Botwa, Hotutu, Sinoko, Wehoya and Yuya. These areas are located approximately 15km East of Kitale town (01°00'N 35°00'E), in the Trans Nzoia district of Western Kenya, at an altitude varying from 1800 to 1900m above sea level (Jaetzold et al. 2010). This area experience a mean annual temperature of 19°C and an average yearly rainfall of 1000-1200mm, occurring mainly during one rainy season, from mid-March to October (Jaetzold et al. 2010).

Agricultural practices in the Trans Nzoia district started with the construction of the Kenyan-Ugandan railway in 1925. Before then, it was a sparsely populated area relaying mainly on livestock grazing. Agriculture was implemented in the area with large-scale farms led by British settlers and, after the Kenyan independence in 1963, the farms were split and distributed as settlements for Kenyans. Agroforestry practices have been promoted and implemented in the settlement schemes by the NGO Vi-Agroforestry since the 1980s (Makenzi and Omollo 1997, Vi-Agroforestry 1998).

In this region, maize is the main crop, usually intercropped with beans. Other vegetables, including kale, are however also very important crops. Kale is

considered to have a very good potential for high yield in the region when it is planted in the beginning of the rainy season (Jaetzold et al. 2010).

We selected four farms per settlement, with a minimum distance of 100 m between the fields. The selection took place on March 4 and 5, 2014. As this period is at the end of the dry season, growing kale was not very common, thus limiting the choice to fields either irrigated or close to water sources. This limitation also implied a short distance between chosen fields. Even though the variety of kales differed, with both annual and perennial varieties available, the selected fields all contained crops approximately 40-50 cm high. All farmers had used chemical insecticide at least once on their kale fields, but the regularity of the spraying varied greatly and we recorded the use of insecticide during the fieldwork period, as well as the use of mulch. The farm location was recorded with GPS (Garmin Oregon 200) and the amount of rainfall was recorded by placing a rain-measurement cup in Kitale and recording rainfall twice a day. All the data were retrieved during the months of March and April 2014.

Assessment of agroforestry and landscape complexity

The level of implementation of agroforestry practices was described with two different parameters: the level of shade on the kale field and the proportion of wooded vegetation within a 50 m radius.

The presence or absence of shade was first noted by eye-estimation during the farm selection, in order to have the same number of open and shaded fields. The classification was then more precisely defined by recording the amount of shadiness at another time of the day during the course of the fieldwork (fig. 1). Open fields were those with no shade at all during the warmest hours of the day.

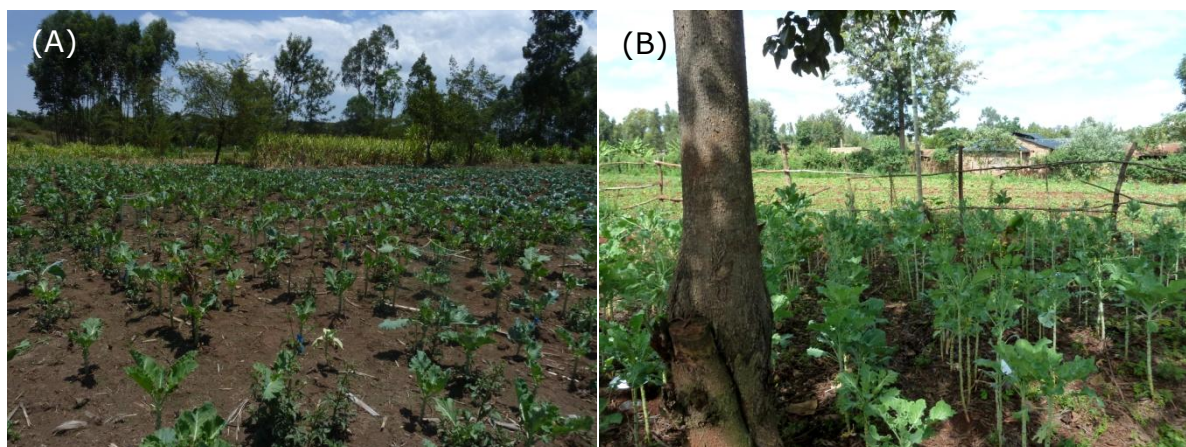


Fig. 1: Examples of selected fields, classified as (A) open (Botwa) and (B) shaded (Yuya).
(Pictures: S. Guenat, 2014)

The proportion of wooded vegetation was calculated based on land-use maps developed by Meshack Nyabenge and Jane Wanjara from the GIS-unit at the World Agroforestry Centre (ICRAF) in Nairobi and based on Quickbird imagery

from August 2010 and December 2011. Buffers with a radius of 50 m around the sampled field were applied and the proportion of wooded vegetation extracted from those (Appendix 1). Even though predators and parasitoids have been shown to be influenced by the landscape up to 6 km (Thies et al. 2003, Zaller et al. 2008, Chaplin-Kramer and Kremen 2012, Josso et al. 2013, Rusch et al. 2013), a range of 50m was chosen for two reasons: (1) the extent of the land-use maps was not sufficient to deal with a greater range of analysis and (2) the short distance between the fields implied that, in any larger scale analysis, the analyzed zones would be overlapping for most farms. Even with such a limited radius, the landscape analysis included an area of slight overlap (543 m²) for one of the pairs. The land-use categories considered as wooded vegetation were hedges, shrubland, shrubs, trees and woodland. All landscape analyses were carried out with ArcGIS v.10 (ESRI 2011).

Predation was assessed by three different experiments, namely by (1) placing egg clutches on the field and surveying removal rates, (2) setting up bird exclosures and measuring their effects on aphid populations, leaf damage and aphid parasitism and (3) placing plasticine caterpillars on kale plants and surveying predation and parasitism marks. Pest (aphids and caterpillars) and predator (spiders, ants and predatory beetles) populations were also monitored, either with pitfall traps or by counts on randomly chosen plants. Aphid parasitism rates were recorded on the same plants.

Ground and foliage-dwelling arthropods

Survey of ground-dwelling predator fauna

The activity density and composition of the ground-dwelling arthropod fauna were monitored by placing four pitfall traps in each field for 48 h. The traps consisted of 850 ml plastic buckets dug to ground level and containing a funnel and soap water to stop the organisms from escaping. When possible, these were placed after the completion of the egg predation experiment in order not to deplete the arthropod fauna. Due to identification difficulties and higher arthropod abundances, only three groups of predators were selected for further analysis: ants (Hymenoptera: Formicidae), spiders (Arthropoda: Aranae) and predatory beetles (Coleoptera: Carabidae and Staphylinidae).

Survey of foliage-dwelling pest and predator fauna

The presence and abundance of foliage dwelling arthropods was assessed by counting the fauna on five randomly chosen kale plants at each field. Those counts took place once in each field between the 7th and the 23rd of April. All arthropods present were recorded, but only aphids, caterpillars (Lepidoptera) and spiders were included in the analysis as other organisms had too low abundances.

Predation by ground-dwelling arthropods on Diamondback moth eggs (*Plutella xylostella*)

In order to see the effect of ground-dwelling predators, predation on pest eggs was assessed. The target species was Diamondback moth (*Plutella xylostella*), whose eggs were obtained from the International Centre for Insect Physiology and Ecology (ICIPE) in Nairobi. The eggs were collected from the 27th and 28th of March and received in Kitale on the 1st of April. They were kept in the fridge from then until they were used, on April the 4th. Clutches of approximately 10 (+/-3) eggs were glued (UHU Super Glue liquid Ultra fast-minis) on 1 cm x 10 cm white plastic labels. Five egg clutches were placed on the ground of each field and fixed with toothpicks. One of the five clutches was enclosed within a 1 mm - 2 mm mesh cage to exclude all factors of removal and act as a control. The number of control clutches was lower than the open ones because of material limitations. All clutches were protected from the rain by a 23 cm diameter round plastic plate. The eggs were collected and counted after 24 h to assess removal rate.

Predation by birds on aphids and caterpillars

In order to assess the effect of bird predation on aphid abundances, parasitism on aphids and damage by free-feeding caterpillars, an exclusion experiment was performed. Four pairs of plants per farm were selected, with a minimum of one meter between each pair and two between each replicate, as long as the field size allowed it. In the four fields too small to allow it, the pairs were still separated by 1 m and the replicates by the largest distance available, at minimum 1 m. On each plant, six leaves were selected in a systematic way and marked with a water-proof pen. Living and mummified aphids were counted on both sides of three of the marked leaves and herbivory by chewing arthropods was estimated on the three other marked leaves, according to a visual estimation of the proportion of the leaf eaten following a scale of 0%, 0-10%, 10-25%, 25-50%, 50-75% and 75-100%. Birds were then excluded from one of the paired plants by installing a cage (~45 cm x 45 cm x 55 cm, nylon bird mesh, mesh size 4 cm) around them (fig. 2). This setup stayed on the field for seven days, before assessing leaf herbivory and aphid numbers again. This experiment was conducted twice with a one week exposure time and was prolonged to 14 days exposure the second time on 14 farms to assess whether the effect increased with time. All farms were not assessed for the full 14 days because of time and material limitations.



Fig. 2: Cage used for bird exclusion, Botwa. (Picture: S. Guenat, 2014)

Predation on caterpillars

Predation on caterpillars was assessed by placing surrogate caterpillars on ten plants per field. These caterpillars were modeled out of green plasticine (brand Pilens plasitilina) with a size of 40 mm length and 3 mm - 5 mm diameter. This method has already been used in several studies and has been found to be efficient for providing relative predation rates, thus allowing comparisons between different environments (Loiselle and Farji-Brener 2002, Koh and Menge 2006, Posa et al. 2007, Howe et al. 2009).

The kale plants on which the surrogate caterpillars were positioned were selected with a minimum distance of 1 m from each other and the surrogate caterpillars were placed on the third leaf from the top, as long as they were large enough for the caterpillar to fit on. This experiment was conducted three times and predation marks were recorded twice, after two and seven days. Marks were also noted before exposure, in order to ensure that the marks after exposure had been inflicted by predators. All marks were recorded in the field with the help of a 10x magnifying glass and were photographed for later identification.

Predation marks were identified with the help of Howe et al. (2009) and Tvardikova and Novotny (2012). Trials were also carried out by capturing some ants, spiders and a predatory beetle and placing them in enclosures with a surrogate caterpillar to get examples of their predation marks. These predators were selected for being the most commonly observed. Marks from four organisms groups could be identified with certainty and were consequently selected for analysis: birds, rodents, arthropods and parasitoids (Appendix 2). Data was summarized as presence/absence of marks on each surrogate caterpillar. Disappearance rate of caterpillars was relatively low, with an average removal rate per field of 1% after two days, 6.25% (less than 2 out of 20 caterpillars) after seven days and a maximum of 30% (6 caterpillars out of 20) in a field recently ploughed. Disappearance could be due to various causes such as heavy rains, ploughing or removal by predators. Non-recovered caterpillars were consequently excluded from the analysis.

Parasitism on aphids

Aphid parasitism rate was assessed twice in each field, by counting the living aphids and the parasitized ones (mummies), recognizable by their change in coloration. The first time, one leaf per plant was counted (the second one from the bottom) until either reaching a total aphid count of 1000 or counting aphids on 50 leaves. The second time, the count was effectuated on the whole plant following the same rules, but with a minimum count of five plants.

Statistical analysis

To examine the effect of bird predation on density of aphid populations, parasitism of aphids and damage by free-feeding caterpillars, I compared treatments excluding birds or allowing them free access using Mann-Whitney nonparametric tests, carried out on SPSS v. 20 (IBM 2011). The impact of bird

predation on aphids was then quantified as the difference of aphid population growth rate with the presence or the absence of birds, calculated according to the following formula: $\Delta r = r_{(exclusion\ cages)} - r_{(open\ plants)}$, as described in Östman et al. (2001). The data was plus-one transformed in order to estimate growth rates when the initial population was zero.

Similarly, to assess the efficiency of egg predation by ground-dwelling arthropods, I compared caged and open treatments with Mann-Whitney non parametric tests.

I fitted generalized linear models or mixed-effect models to test the effect of shade, the proportion of wooded vegetation within a 50 m radius, the interaction between the shade and the proportion of wooded vegetation, the insecticide use during the experiment, the use of mulching practices and the amount of rainfall on different variables related to pest control. Specifically the response variables included the abundance of pests and predators (aphids, caterpillars, ants, predatory beetles and spiders) in the pitfalls and on the leaves, the egg predation rates, the impact of birds predation on aphid population growth rate (Δr), the proportion of surrogate caterpillars predated or parasitized by different organisms after two and seven days and the aphid parasitism rate. All analyses were conducted in R.2.14.0 using either the glm-function for generalized linear models or the glmer-function in the lme4-package for generalized linear mixed-effect models (R Core Team 2011). Mixed-effect models including an observation level random factor were used when over-dispersion was detected in the data. The proportion of wooded vegetation within a 50 m radius was arcsine square root transformed. For all response variables expressed as proportions I used models with a binomial error distribution, for all variables expressed as counts a Poisson distribution and for Δr a gaussian distribution. For each response variable, I used a model simplification procedure to select the models that best explained the variation of the data, by comparing all possible models with the Akaike Information Criterion adjusted for small sample size (AICc). Competing models were those with a difference in AICc relative to the best AICc score ($\Delta AICc$) equal or lower than two.

Results

Ground and foliage-dwelling arthropods

Survey of ground-dwelling predatory fauna

In total, I caught 2'081 ants in the pitfall traps. Three competing models gave the best explanation of the activity density of ants. However, none of the variables retained in these models showed any significant effect on the number of ants caught (Appendix 3).

A total of 222 spiders were caught in the pitfall traps. Activity density of spiders was best explained by two different models, each retaining a negative effect of pesticide use ($p=0.017^*$ and $p=0.029^*$; fig. 3).

In total, I caught 48 predatory beetles in the pitfall traps. A similar negative effect of pesticide use was observed for abundances of predatory beetles with this variable being retained in all three best models ($p=0.037^*$, $p=0.074$ and $p=0.028^*$; fig. 4). None of the other explanatory variables retained in the three models had significant effects (Appendix 3).

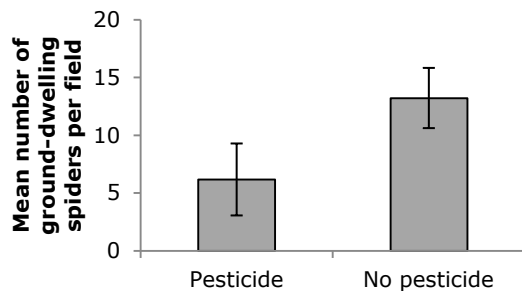


Fig. 3: Mean number of ground-dwelling spiders caught in pitfall traps per field \pm SE in relation to pesticide use. Pesticide use had a significant negative effect on activity density of ground-dwelling spiders ($p=0.017^*$ and $p=0.029^*$ for the two best-fitting models).

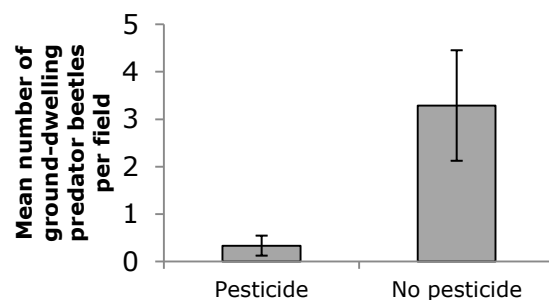


Fig. 4: Mean number of ground-dwelling predatory beetles caught in pitfall traps per field \pm SE in relation to pesticide use. Pesticide had a significant negative effect on predatory beetles abundances ($p=0.037^*$, $p=0.074$ and $p=0.028^*$ for the three best-fitting models).

Survey of foliage-dwelling pest and predatory fauna

In total, I counted 57 spiders on the plants. There was evidence of shade at the field scale having a negative effect on abundance of foliage-dwelling spiders in two of the four best models ($p=0.054$ and $p=0.042^*$; fig. 5). In one of the four best models (Appendix 3), the amount of wooded vegetation at the landscape scale also showed a trend towards negatively influencing the foliage-dwelling spiders ($p=0.090$; fig. 5).

I counted a total of 11'250 aphids. Both best models included a significant negative effect of shade ($p<0.001^{***}$ for both models) and pesticide ($p=0.001^{**}$ and $p=0.005^{**}$; fig. 7). There was also evidence of rain having a negative effect on aphid abundance in one of the two best-fitting models ($p=0.033^*$; fig. 6).

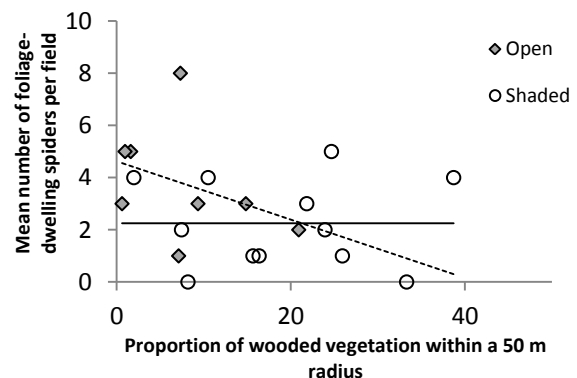


Fig. 5: Weak negative effect of shade on foliage-dwelling spiders ($p=0.054$ and $p=0.042^*$ in two of the four best models) and trend towards a negative influence of wooded vegetation (one out of four models, $p=0.09$). The lines represent the trend in relation to the proportion of wooded vegetation in the landscape for open (dotted line) and shaded (solid line) fields.

I counted a total of 40 foliage-dwelling caterpillars. There is very strong evidence that shade is negatively affecting caterpillar abundance, as it was present and significant in all four of the best models ($p=0.027^*$, $p=0.002^{**}$, $p=0.003^{**}$ and $p=0.024^*$; fig. 8). There is also some evidence of a positive effect of pesticide use, as it was a trend in two models out of four ($p=0.054$ and $p=0.078$; fig. 8). The effect of mulch was not significant, even if it was present as an explanatory variable in some of the best models (Appendix 3).

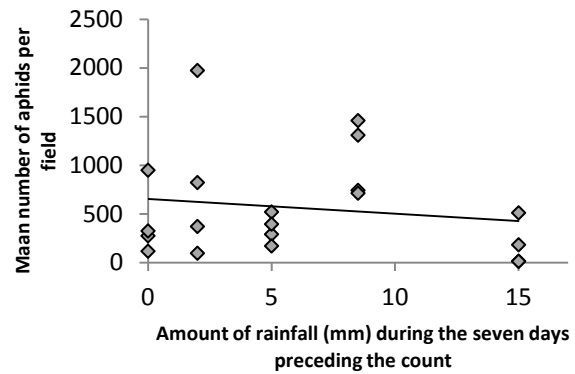


Fig. 6: There was as evidence of rainfall having a significant effect in decreasing aphid populations ($p=0.033^*$ in one out of two models).

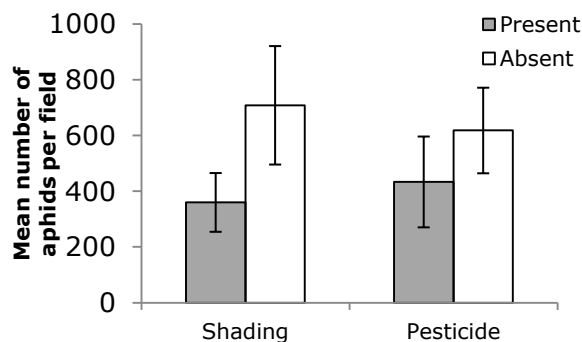


Fig. 7: The mean number of aphids per field \pm SE was negatively correlated with the presence of shade ($p<0.001^{***}$ for both models) and the use of pesticides ($p=0.001^*$ and $p=0.005^{**}$).

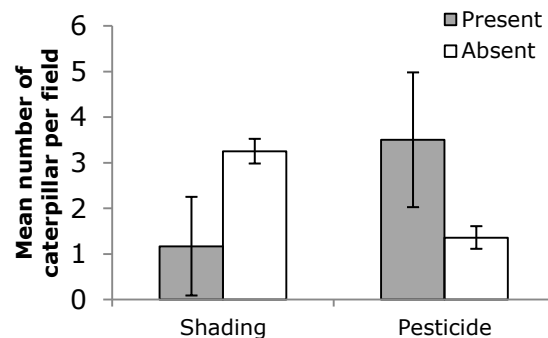


Fig. 8: The mean number of caterpillars per field \pm SE was negatively correlated with the presence of shade ($p=0.002^{**}$, $p=0.003^{**}$, $p=0.007^*$ and $p=0.024^*$), but positively influenced by pesticides ($p=0.003^{**}$ and $p=0.078$ in two models out of four).

Predation by ground-dwelling arthropods on Diamondback moth eggs (*Plutella xylostella*)

The difference between the disappearance of eggs placed on the ground in the cages and in the open treatments confirmed the importance of ground-dwelling predators, the egg removal rate being 56.6% higher in the open treatments compared to the caged ones (Mann-Whitney, $U=485.5$, $p=0.001^{**}$; fig. 9).

Egg removal rates were best explained by three competing models (Appendix 3). The importance of pesticide use in reducing the rate of egg removal was indicated by two out of three models ($p=0.068$ and $p=0.026^*$; fig. 10). The proportion of wooded vegetation was retained in one of the models but was not significant (Appendix 4). The second best model retained no explanatory variables (Appendix 3).

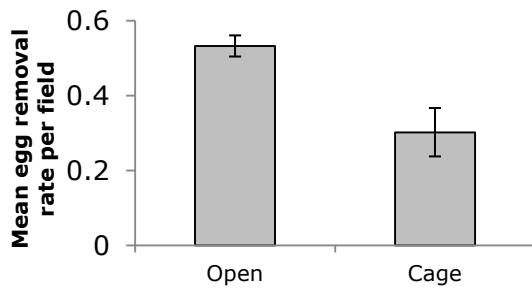


Fig. 9: Mean egg removal rate per field \pm SE in open and caged egg clusters. The effect of ground-dwelling arthropod predation was demonstrated by the significant difference in egg removal rates between open and caged treatments ($p=0.001^{**}$).

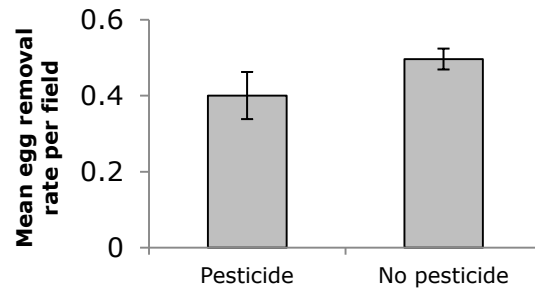


Fig. 10: Mean egg removal rate per field \pm SE in relation to pesticide use. Pesticide use had a significant negative effect on egg removal rates ($p=0.027^*$ and $p=0.069$ in two competing models out of three).

Predation by birds on aphids and caterpillars inferred from exclusion cages

The exclusion of birds from kale plants showed that birds have a positive effect in decreasing the aphid population after seven days (Mann-Whitney, $U=10355.5$, $p=0.018^*$; fig. 11). This effect however became imperceptible after 14 days. Altogether, no effect of the bird-exclusion cages was found on herbivore-related leaf damage or on aphid parasitism rates.

The bird predation on aphids was not influenced by any of the explanatory variables (the single best model included only the intercept; Appendix 3).

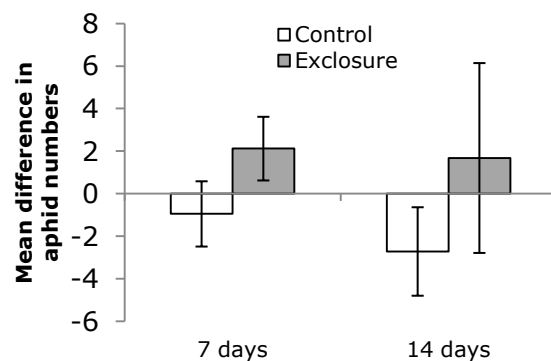


Fig. 11: Mean number of aphids \pm SE in the bird exclusions and the control. After seven days, a significantly higher number of aphids was observed on plants from which birds were excluded ($p=0.018^*$), but this significance disappeared after 14 days (however the latter was based on a lower number of sampled fields).

Predation on surrogate caterpillars

There is some evidence of shade having a positive effect on bird predation on surrogate caterpillars after two days, as it was significant in one out of the three best models ($p=0.033^*$) and nearly significant in another ($p=0.059$; fig. 12). None of the other retained variables showed any effect. The effect of shade on bird predation on surrogate caterpillars however did not persist, as none of the best models included any significant explanatory variables after seven days (Appendix 3).

Predation by invertebrates on surrogate caterpillars increased with increasing rainfall during the seven day period ($p<0.001^{***}$; fig. 13) according to the single best model (Appendix 3), while no effect was seen during two days.

None of the explanatory variables demonstrated any significant effects on rodent predation or parasitism on surrogate caterpillars neither after two days nor after seven days (Appendix 3).

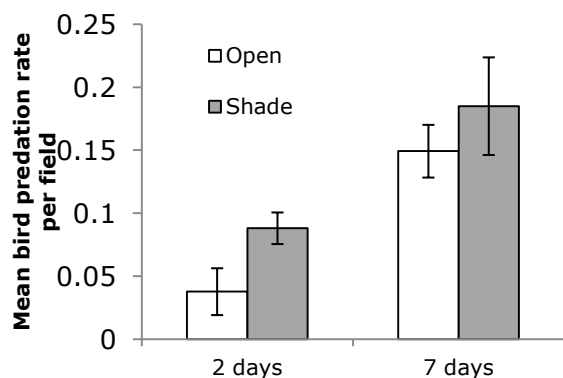


Fig. 12: Mean bird predation rate on surrogate caterpillars per field \pm SE in relation to shade. The bird predation rate on surrogate caterpillars was higher in shaded fields than in open ones after two days ($p=0.059$ and $p=0.033^*$ in two out of three models). Despite having higher predation rates, this trend disappeared after seven days.

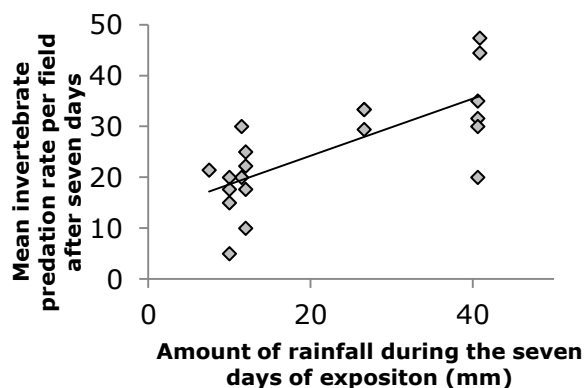


Fig. 13: Invertebrate predation on surrogate caterpillars after seven days was positively correlated with the amount of rainfall during those seven days ($p<0.001^{***}$).

Parasitism on aphids

For aphid parasitism rate, a total of 24'661 living and mummified were counted on the plants, with an overall parasitism rate of 0.0215. The best model included shade and pesticide use as explanatory variables. This model was not competing with any other, thus showing strong evidence that the aphid parasitism rate was higher in shaded fields than in open ones ($p<0.001^{***}$) and lower when no pesticide was applied ($p<0.001^{***}$; fig. 14). Both these effects were confirmed while adding aphid abundances as additional explanatory variable to the model.

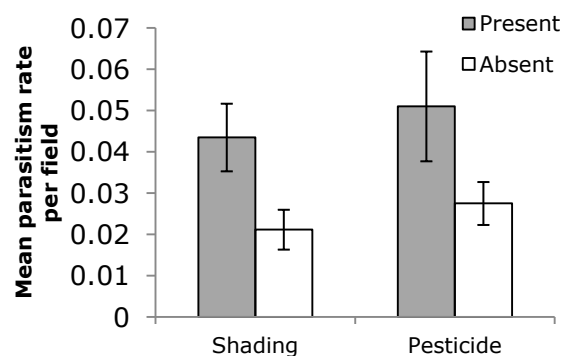


Fig. 14: The mean aphid parasitism rate per field \pm SE was positively influenced by shade ($p<0.001^{***}$) and pesticide ($p<0.001^{***}$).

Discussion

This study confirmed my first hypothesis, that shading would be beneficial in reducing pest populations, as both surveyed pests had lower abundances in shaded fields. Not only were the pest abundance shown to be lower in the presence of shade, but predation by birds on caterpillars and parasitism on aphids were also shown to increase with shade. The other two hypotheses, concerning the positive effect of the proportion of wooded vegetation in the landscape and its interaction with the local shading practices, were however not confirmed.

Effect of shade in reducing pest populations

My results showed that tree plantations inside or directly adjacent to kale fields can effectively reduce pest populations. This may be due both to top-down effects mediated by natural enemies and to bottom-up effects directly affecting the pests (Schroth et al. 2000). The aphid parasitism rate and the bird predation on caterpillars were positively affected by the presence of shade in my study. However, none of the surveyed ground-dwelling predators showed any sensitivity to shade. This, together with the fact that only few of the experiments on actual predation showed differences due to shade, suggests that the observed differences were partly bottom-up effects of shade on pest populations. Indeed, abiotic factors such as shade are known to affect plant quality and palatability, and thus be mediators of pest abundances (Dunson and Travis 1991). Such differences in plant quality can be due to intrinsic responses of the plant to local conditions, such as higher sugar content in open areas, rendering the plants more attractive to pests. Other studies have also shown that sun-exposed plants can have more pests compared to shaded ones, even when predators are not affected by shade (Barber and Marquis 2011).

The positive influence of shade on parasitism on aphids was harder to predict as previous studies have showed various results. In general, parasitism seem to be related to parasitoid species richness (Klein et al. 2002), which has not been assessed by this study. Some studies showed higher parasitoid abundances in agroforestry systems than in conventional ones and higher parasitoid diversity with increased tree densities (Sperber et al. 2004), but other studies showed no influence of light intensity (Klein et al. 2006). Similarly, parasitism rates in other host-parasitoid systems have both been shown to be positively correlated (Ogol et al. 1998, Stoepler and Lill 2013) and negatively correlated with light intensity (Ogol et al. 1998). In any case, the positive effect of shade on aphid parasitism rates in kale in my work suggests that it is one of the mechanisms behind the decrease in aphid populations due to shade. The scope of this mechanism could be further assessed with parasitoid surveys. The detected effect of shade on parasitism is however further confirmed by the fact that it remained significant also after controlling for aphid abundances.

It is most probable that birds also contributed to aphid and caterpillar suppression and were affected by shade, even though this effect was only detected for predation on the sentinel caterpillars. The positive influence of agroforestry systems on avian predation have already been noted, be it by showing the similarity in bird predation rates between forest and agroforestry systems (Van Bael et al. 2008) or by demonstrating an increased bird predation with higher proportion of trees or direct shading in agro-systems (Perfecto et al. 2004, Bianchi et al. 2008, Karp et al. 2013). This effect is confirmed by the

significant positive effect of shade on Lepidopteran predation by birds noticeable after two days in my study. The fact that bird predation on caterpillars was affected by shade, whereas arthropod predation and parasitism of caterpillars was not, could indicate an effect of bird intra-guild predation on both arthropod predators and parasitoids. Any possible difference in their abundances due to shade would then not be discernible because of the negative feedback created by avian predation on arthropod predators and parasitoids. Such interactions between trophic levels have been observed in other ecosystems (Tscharntke 1992, Rosenheim et al. 1995, Martin et al. 2013). However, if many studies have focused on predator-pest and parasitoid-host interactions, few are available on intra-guild predation and how these relationships can affect pest populations in agro-forestry systems.

The detection of shade effects by the surrogate caterpillar experiment could also have been impeded by an intrinsic bias due to the method. Studies have shown that surrogate caterpillars were efficient for comparing the influence of different environments on rates of predation and parasitism by different organism groups, but that they probably tend to underestimate the absolute predation and parasitism rates that would occur on live caterpillars. One of the problems with the method is the increased importance of visual cues compared to e.g. chemical cues such as synomones from the attacked plant or presence of frass (Howe et al. 2009). Most of the studies using this method focused on different environments in forest systems (Loiselle and Farji-Brener 2002, Koh and Menge 2006, Posa et al. 2007, Richards and Coley 2007, Fáveri et al. 2008, Tvardikova and Novotny 2012, Barbaro et al. 2014) and one could speculate that open agricultural landscapes may have a different effect on surrogate caterpillar predation. The visual acuity of predators adapts to the light conditions they're in, implying that if they're in high light environments such as open fields, all shaded environments are rendered out of perceivable range, in effect hiding caterpillars from being visually detected. It could consequently explain why the detected effect of shade was not strong enough to withstand the seven days surrogate caterpillar experiment albeit some other studies showed positive effect of trees on birds (Şekercioglu et al. 2002, Van Bael et al. 2008, Karp et al. 2013). Additionally, parasitoids are known to respond mainly to olfactory cues and to have learned search images on which they focus (Ishii and Shimada 2010). Their effect is thus probably diminished by the lack of such cues from the surrogate caterpillars, possibly to an amount rendering all differences according to any of the explanatory variables undetectable.

Possible improvements to the study design

The timing of this study could have had important consequences for the results. The current study was conducted between the end of the dry and beginning of the wet seasons. The two different seasons in tropical areas are known to affect pests and predator relationships. Studies in Central Kenya for instance showed that, during the dry season, birds decreased both aphid populations and leaf damage but this effect was no longer significant during the wet season (Ndang'ang'a et al. 2013). These authors postulated that the two main mechanisms behind this seasonal difference were the lower availability of alternative food resources for birds during the dry season and the dislodging of invertebrates from kale leaves by heavy rains during the wet season. Indeed, rainfall was identified as being an important explanatory factor for some of the tested variables in my study; it had a negative influence on predation of

invertebrates on caterpillars and aphid abundance. Several farmers also mentioned a general decrease in aphid populations with the rain, thus adding weight to the assumption of a seasonal difference in pest populations. Another hint that predation varies seasonally is the fact that aphid predation by birds was significant during my seven days experiment, which took place at the end of the dry season, but not during the 14 days one, which took place during the last three weeks of April, when the rains had already started. The fact that the fieldwork in my project spanned both seasons might consequently have influenced the results by decreasing any effect that may have been visible during the dry season. A survey of the bird abundances and diversity per field could also help shed light on their relative importance of biological control and their responses to environmental conditions.

As my study started during the end of the dry season, kale fields were only present close to permanent water sources. This restricted the choice of fields for the experiment had a strong impact on the landscape analysis as many farms were closer than 200 m from each other, thus forcing a land-use analysis either at a 50 m radius or with overlapping zones. The first option was chosen in order not to have any dependence between the different zones, but predation and parasitism is known to be influenced by landscape diversity at a scale of 300 m to 10 km (Thies et al. 2003, Bianchi et al. 2008, Zaller et al. 2008, Chaplin-Kramer and Kremen 2012, Josso et al. 2013, Rusch et al. 2013). The small scale of the landscape analysis in my study might thus be an explanation to why no significant effect of tree cover in the landscape was detected despite other studies showing positive effects of landscape diversity (Thies et al. 2003, Zaller et al. 2008, Chaplin-Kramer and Kremen 2012, Jonsson et al. 2012, Josso et al. 2013, Rusch et al. 2013) and landscape-level tree cover on reducing pest populations (Bianchi et al. 2008, Van Bael et al. 2008, Rusch et al. 2013). One of the mechanisms explaining the benefit of agroforestry for predators is the increased connectivity of landscape components (Bhagwat et al. 2008). Yet, my study offers only little indication of the connectivity between forest patches as dispersal distances of the predators studied are probably much larger than the analyzed landscape scale. Moreover, because of the cooperation between SLU and Vi-Agroforestry, all farms were selected within settlements in which Vi-Agroforestry had worked. Consequently, even though some farmers did not implement agro-forestry practices, such practices were always implemented in the vicinity. Instead of comparisons within settlements, a comparison between settlements applying agroforestry and settlements not using such practices could have been more pertinent. Such a selection would also have allowed a greater distance between the study fields, and thus the use of a greater scale for landscape analysis.

Possible ways of improving biological control in agroforestry systems

Even though my work showed that local shade reduced the abundance of two pests, the effects of local shade on predators and predation rates were more inconsistent, and neither predation rates nor pest or predator abundance were influenced by the proportion of wooded vegetation in the landscape. Similarly, there are examples from the literature where neither landscape diversity (Landis et al. 2000, Martin et al. 2013) nor local agroforestry practices (Midega et al. 2004) resulted in enhanced pest control. These inconsistent results could be due to several mechanisms.

Firstly, when agroforestry is implemented to produce e.g. construction materials, fruits or firewood, tree diversity is often quite low (Kindt et al. 2006). This could be observed at my field sites, where *Grevillea robusta* and *Sesbania* sp. were largely dominant. The first species is an exotic used mainly for timber while the second, an indigenous species, is used for its nitrogen-fixing properties, and both are recommended by Vi-Agroforestry. In such conditions, even though the biodiversity is slightly increased compared to monoculture, it still stays quite low and so might not have an important effect. The plantation of a higher diversity of trees could thus be beneficial for improving biological control.

Secondly, several studies have shown that an increase in biodiversity may not be sufficient in itself to augment biological control (reviewed in Landis et al. 2000 and Letourneau et al. 2009). As pests and predators may be reactive to different cues, the increase of certain plant species may rather increase pest populations than predators', or have no effect altogether (Landis et al. 2000). In this regard, it is possible that the increase in biodiversity induced by the implementation of agroforestry may not offer favorable conditions for predators. A selection of tree species known to be pest repellent or to provide essential resources for natural enemies should thus be favored.

Predation by birds

In my study, avian predation significantly decreased aphid populations, albeit not leaf damage. Substantial avian predation on aphids have already been shown in other regions of Kenya, where such predation also impacted the leaf damage (Ndang'ang'a et al. 2013). Such beneficial effect of birds on reducing pest damage, together with its other beneficial functions such as seed dispersal, pollination or ecosystem engineering to cite only a few, has been demonstrated worldwide in both open and shaded agricultural landscapes since the early 19th century (Şekercioglu 2006, Mäntylä et al. 2011, Maas et al 2013, Kronenberg n.d.).

Despite this fact, the avian fauna is often considered harmful because of the pest status of some bird species, which can feed on cereals and vegetables, as well as their importance in spreading weeds and diseases, and they have thus been hunted for centuries (Bircham 2007, cited by Kronenberg n.d.). In Kenya, this notion still prevails (Chitere and Omolo 1993, Grisley 1997) and can be seen through measures taken by farmers to scare away birds. Showing that birds can reduce pest damage through predation is thus of prime importance in order to promote bird conservation. A focus on agricultural landscapes is appropriate as insectivorous birds are affected by an increased area of agricultural land-uses in relation to forested areas and most agricultural bird populations are decreasing drastically (Şekercioglu et al. 2002, EBCC 2013). This decrease could have important economic implications. For example, estimations of the value of birds vary from US\$75 to 310/ha/year in Costa Rican coffee plantations (Karp et al. 2013). This value may not be comparable to Kenyan kale plantations. However, seeing that more than 30% of the Kenyan population lives with less than US\$730 per year (FAO 2012), such increases in costs could be intolerable when agriculture is the main provider of their livelihoods.

Effect of pesticides

This study demonstrated some negative effects of pesticides on pest control, as they decreased predator populations (spiders, rove beetles and ground

beetles) and predations rates on diamondback moth eggs while increasing caterpillar populations and aphid parasitism rates. However, a survey of caterpillar populations before pesticide application would be needed to rule out any correlation between the initial amount of caterpillars and the application of pesticides. In contrast, insecticide application was efficient in reducing aphid populations. Among the surveyed farms, all the farmers used insecticide albeit to different extent, and some used herbicides. The analysis focused on pesticide application during the two months of the fieldwork period and the month before.

The importance of spiders and rove beetles for diamondback moth egg predation has already been shown (Miranda et al. 2011), thus making it logical that a decrease in their population abundances would affect egg removal rates. Some pesticides have already been seen to have strong negative effects on natural enemies, especially parasitoids (Flexner et al. 1986, Theiling and Croft 1988). Natural enemies can be contaminated either by direct contact during the spraying or indirectly by taking up residues while foraging or looking for hosts (Ulber et al. 2010). Avian predators are not immune against pesticides either and can be killed or suffer reproductive disorders due to pesticide poisoning (Kairu 1994, Kwon et al. 2004, Parsons et al. 2010). For both predators and parasitoids, the effects of pesticides are different according to which type of pesticide is used (Bacci et al. 2009, Liu et al. 2012). When affordable, farmers tend to prefer pesticides compared to other pest control methods since they are easy to apply (Kibata 1996). Describing which types of pesticides are counter-effective could decrease their use and, consequently, their negative effects on pest predation as well as on health and the environment. The protection of predators could take place without completely banning pesticides, through the selection of adequate products, and by adjusting the dose, the timing and place of the spraying (Ulber et al. 2010). This may however be difficult in Kenya as the information available on *Brassica* is mostly based on studies from temperate climate and access to this kind of information may be more difficult in Kenyan rural areas.

The significant effect of pesticides on predators could be another reason for the non-significant effect of landscape on predation in my study. For example, Winqvist et al. (2011) found that the effect of landscape diversity was significant only in organically managed fields but not in conventionally managed ones. The fact that insecticides negatively influence predator populations might consequently have decreased the beneficial effects of landscape. Such assumptions have also been made in other studies, pin-pointing the importance of insecticide-free zones for increasing biological control (Valantin-Morison et al. 2007, Winqvist et al. 2011).

Conclusion

This study demonstrated positive effects of shade as a local management practice to reduce pest populations of both aphids and caterpillars on kale. In addition, shade increased bird predation on caterpillars and aphid parasitism rates, thus hinting towards beneficial effects of agroforestry for biological pest control. Further research is however needed in order to examine the broader effects of such practices, with clearer differentiation between agroforestry and non-agroforestry practices, a larger scale for landscape analysis and a sampling-period set during one clearly defined season. The plant responses to shade could also be evaluated to assess more clearly the bottom-up mechanisms behind the

observed reduction of pest populations and the effect of shade on crop quality and yield. Yet even if agro-forestry turns out not to be beneficial for pest control at a landscape level, such practices should not be abolished as its effectiveness at a local scale have been demonstrated by this study, and agroforestry can provide other ecosystem services, such as retrieving nutrients and water from lower soil layers or providing additional resources to the farmers e.g. in the form of fruits or timber (Nair 1993, Bhagwat et al. 2008).

This study additionally highlighted birds as important predators of aphids in kale fields, a result that could contribute to changing the often negative perception toward birds. It also indicated negative effects of pesticides on predator populations, which can have effects on predation and potentially increase caterpillar populations. These results show a promising direction for future studies and can also offer some help to increase the efficiency and sustainability of farming practices.

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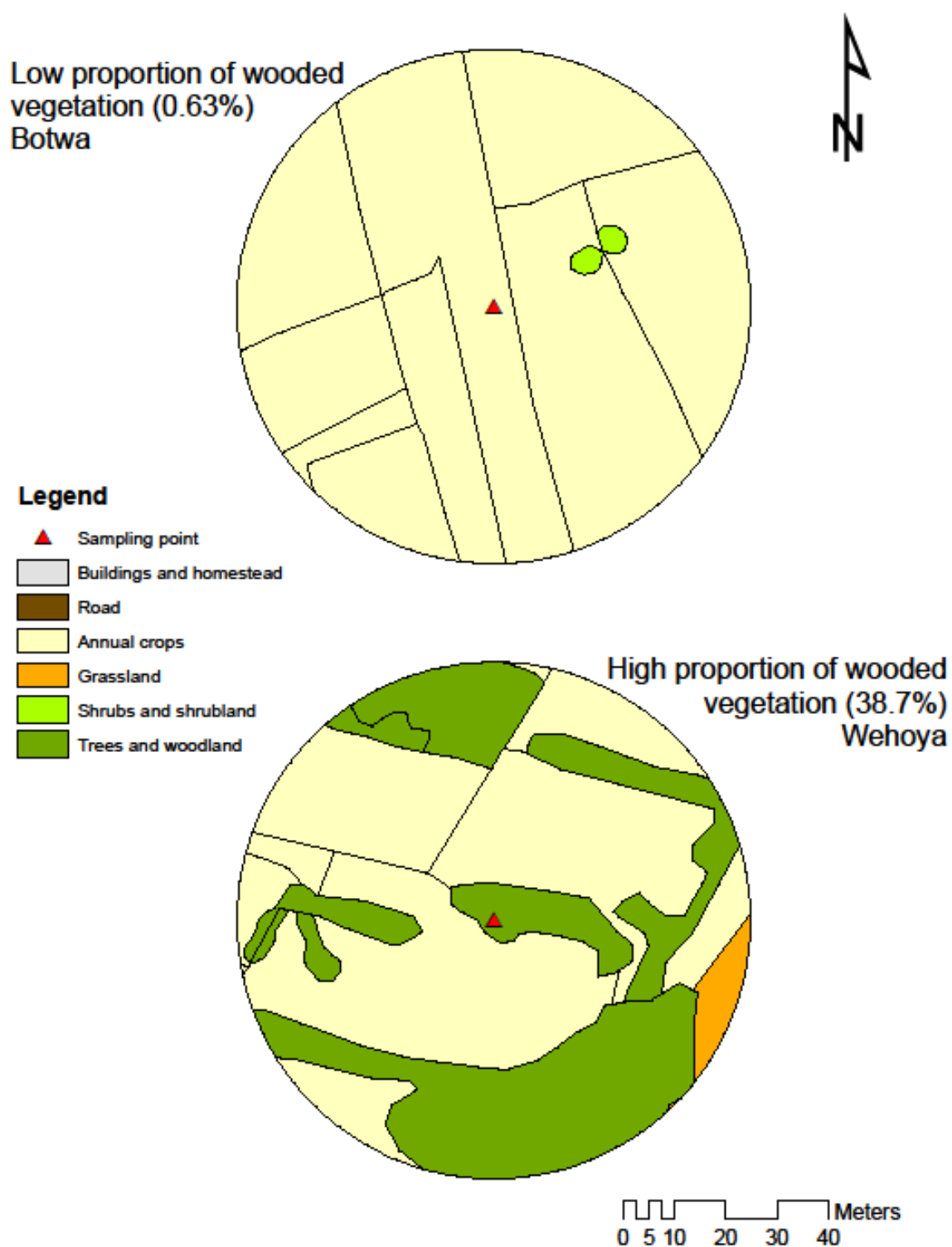
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Appendix 1: Example of landscape analysis buffer zones

Example of landscape analysis zones with high and low proportion of wooded vegetation



Appendix 2: Examples of predation and parasitism marks on surrogate caterpillars

(A)



(B)



(C)



(D)



Fig. 15: Examples of surrogate caterpillars showing signs of predation or parasitism. Marks made by (A) a bird, (B) an arthropod predator, (C) a rodent and (D) a parasitoid. The arthropod marks were the result of the trial with a predatory beetle. Short and long bars indicate 1mm and 1cm respectively. Contrasts were increased using Gimp v2 software.

Appendix 3: Summary of the retained models

Summary table of the best generalized linear models or mixed-effect models, selected on the basis of Akaike Information Criterion adjusted for small sample-size. Models with AICc below two were retained.

K = number of estimated parameters in the model; AICc = Akaike Information Criterion adjusted for small sample-sizes; Δ AICc = difference of AICc with the best-fit model; and Akaike weight = probability of the model to be the best out of all the tested ones. The significance of the explanatory variables is presented according to the following scale: ^t = trend, $p \leq 0.1$; * = significant, $p \leq 0.05$, ** = significant, $p \leq 0.01$ and *** = significant, $p \leq 0.001$.

	K	AICc	Δ AICc	Akaike weight
DMB egg removal rate				
pesticide ^t	3	42.77	0.00	0.25
mean only	2	43.04	0.27	0.22
proportion of wooded vegetation + pesticide*	4	44.09	1.32	0.13
Abundance of ground-dwelling ants				
mean only	2	98.29	0.00	0.26
shade	3	100.18	1.88	0.10
proportion of wooded vegetation	3	100.23	1.94	0.10
Abundance of ground-dwelling spiders				
pesticide*	3	63.87	0.00	0.18
pesticide* + rain	4	64.64	0.78	0.12
Abundance of ground-dwelling predatory beetles				
pesticide*	3	49.52	0.00	0.23
proportion of wooded vegetation + pesticide ^t	4	51.28	1.76	0.10
pesticide* + mulch	4	51.32	1.81	0.09
Abundance of foliage-dwelling spiders				
shade ^t	2	83.11	0.00	0.17
proportion of wooded vegetation ^t	2	83.91	0.80	0.11
mean only	1	84.32	1.22	0.09
shade* + rain	3	85.04	1.94	0.06
Abundance of aphids				
shade*** + pesticide** + rain*	5	142.71	0.00	0.34
shade*** + pesticide**	4	143.21	0.50	0.27

Abundance of caterpillars

shade* + pesticide ^t	3	74.25	0.00	0.20
shade**	2	75.18	0.93	0.13
shade** + mulch	3	75.59	1.34	0.10
shade* + mulch + pesticide ^t	4	75.62	1.37	0.10

Bird exclusion

mean only	2	20.93	0.00	0.31
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Bird predation rate on surrogate caterpillars***Two days***

shade ^t	2	58.78	0.00	0.19
mean only	1	60.36	1.58	0.09
shade* + proportion of wooded vegetation	3	60.61	1.83	0.08

Seven days

mean only	1	78.81	0.00	0.25
shade	2	80.44	1.63	0.11
mulch	2	80.80	1.99	0.09

Invertebrate predation rate on surrogate caterpillars***Two days***

mean only	1	80.12	0.00	0.26
proportion of wooded vegetation	2	81.92	1.80	0.10

Seven days

rain***	2	77.30	0.00	0.39
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Rodent predation rate on surrogate caterpillars***Two days***

mulch	2	26.77	0.00	0.26
mean only	1	28.66	1.89	0.10

Seven days

mean only	1	41.62	0.00	0.15
shade	2	42.17	0.55	0.12
rain	2	42.32	0.70	0.11
shade + pesticide	3	43.40	1.78	0.06
shade + rain	3	43.48	1.86	0.06

Parasitism rate on surrogate caterpillars***Two days***

mulch	2	35.57	0.00	0.31
shade + mulch	3	37.19	1.62	0.14

Seven days

mean only	1	53.43	0	0.27
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Aphid parasitism rate

shade*** + pesticide***	4	62.99	0	0.55
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Appendix 4: Effects of shade, proportion of wooded vegetation and their interaction

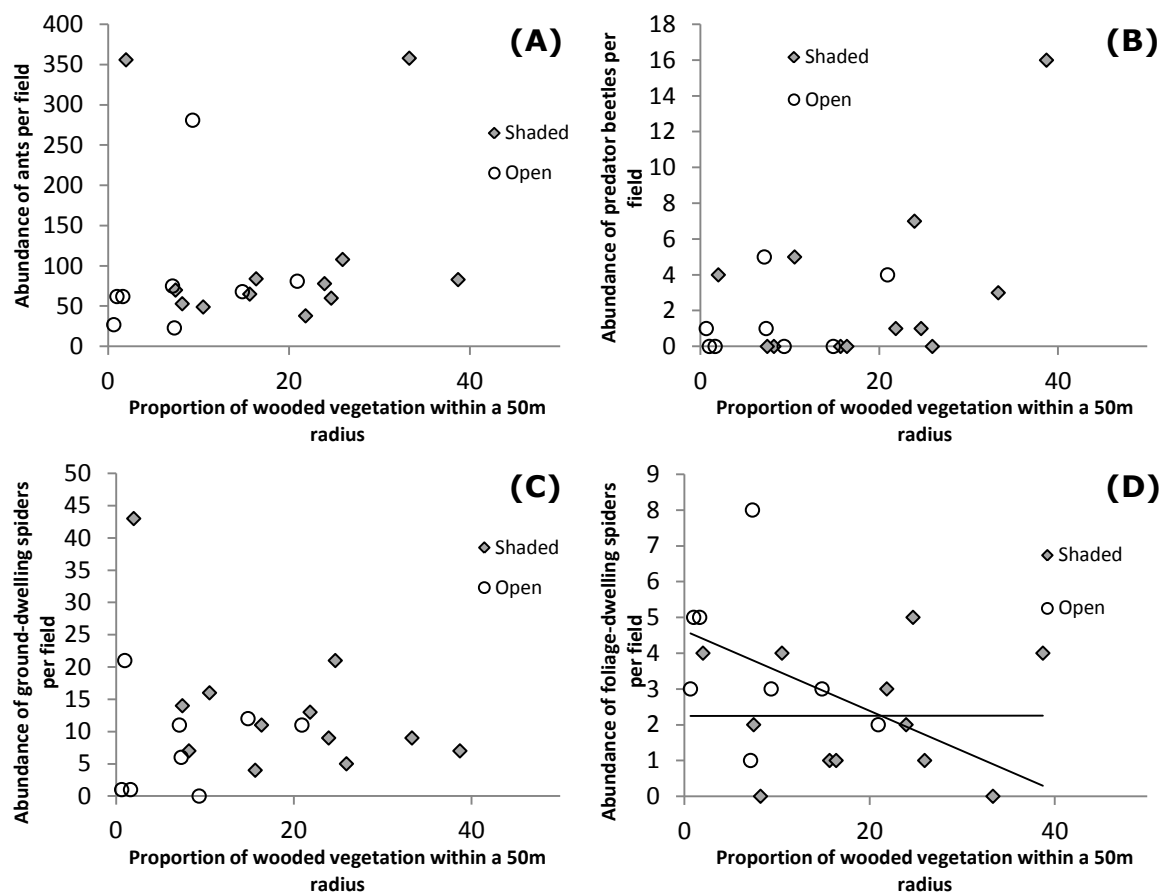


Fig. 16: Abundances of different predators per field and the impact of both shade and proportion of wooded vegetation within a 50m radius: (A) ground-dwelling ants; (B) ground-dwelling predatory beetles (Coleoptera: Carabidae and Staphylinidae); (C) ground-dwelling spiders; and (D) foliage-dwelling spiders. There was some evidence of the abundance of foliage-dwelling spiders (D) being negatively influenced by shade and proportion of wooded vegetation (straight lines).

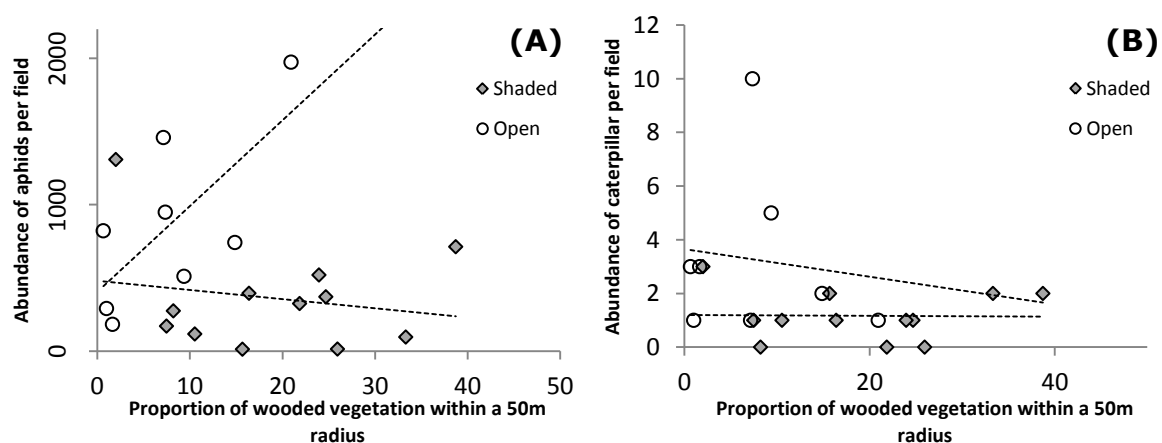


Fig. 17 : Abundances of different foliage-dwelling pests per field and the impact of both shade and proportion of wooded vegetation within a 50m radius: (A) aphids; and (B) caterpillars. Shade negatively influenced both pest populations (dotted lines) but there was no effect of the proportion of wooded vegetation.

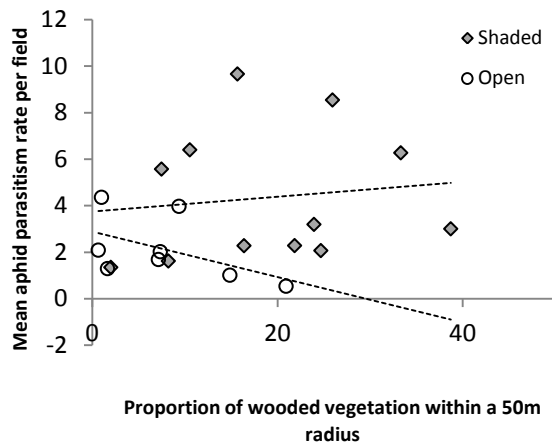


Fig. 18 : Aphid parasitism rates per field and the impact of both shade and proportion of wooded vegetation within a 50m radius. Shade positively influenced aphid parasitism rates (dotted lines) but no effect of the proportion of wooded vegetation was detected.

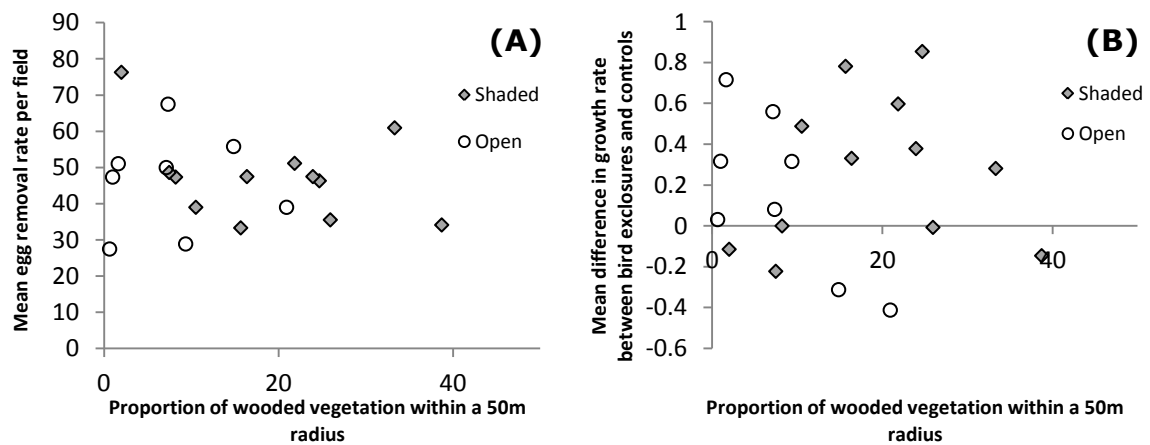
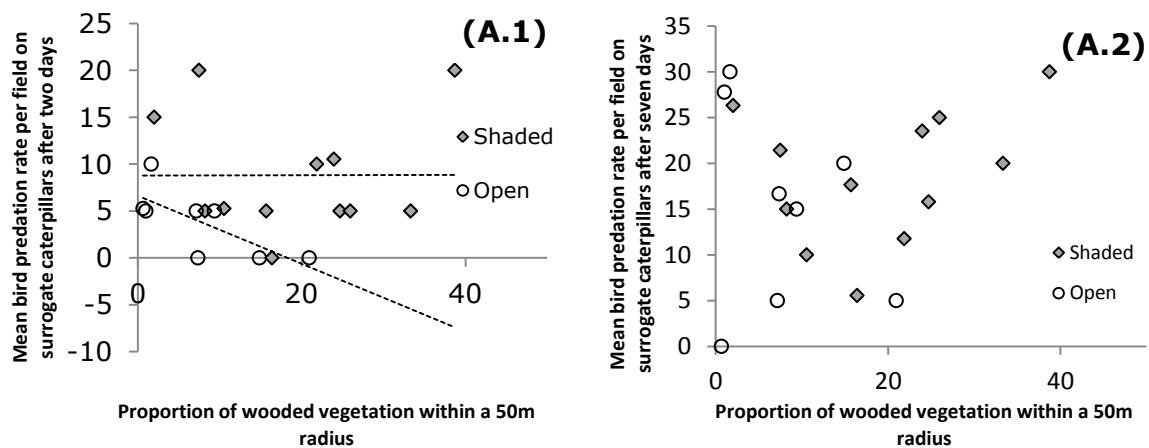


Fig. 19 : Different measures of pest predation and the impact of both shade and proportion of wooded vegetation within a 50m radius: (A) diamondback moth egg removal rate by ground-dwelling arthropods and (B) difference in aphid growth rates with or without the exclusion of bird. Neither the effect of shade nor that of the proportion of wooded vegetation was significant in any of the two cases.



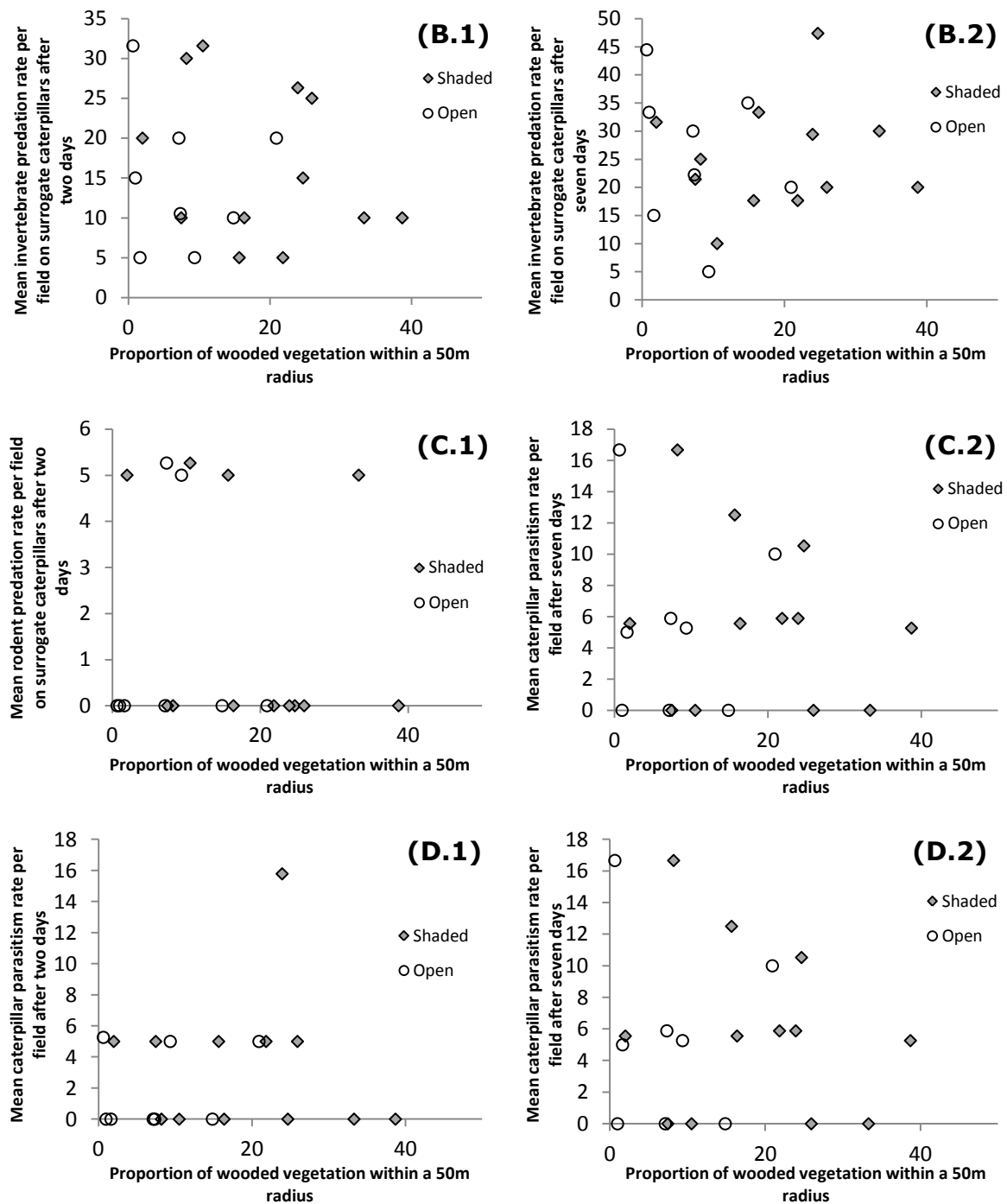


Fig. 20 : Predation and parasitism rates per field on surrogate caterpillars by the four selected groups of natural enemies and the impact of both shade and proportion of wooded vegetation within a 50m radius: (A) bird predation rate; (B) invertebrate predation rate; (C) rodent predation rate and (D) parasitism rate. The left hand-side column (1) displays predation and parasitism rates after two days of exposition, the right hand-side column (2) after seven days. Shade showed evidence of positively influencing bird predation after two days (A.1, dotted lines) but not any of the other natural enemies. The effect of the proportion of wooded vegetation was never significant.